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New Results on the B_c^- Meson at the Tevatron

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We present recent results on B_c^- meson from the Tevatron. The B_c^- meson has been observed in semileptonic decays, $B_c^- \to J/\psi l^- \nu X$, both by CDF and DØ experiments at a significance larger than 5σ. The DØ experiment has used the candidates in $B_c^- \to J/\psi \mu^- \nu X$ decay to extract the mass and lifetime of B_c^- meson. The CDF experiment has used both electron and muon channel candidates in $B_c^- \to J/\psi l^- \nu X$ decays to measure the relative production times branching ratio with respect to $B^- \to J/\psi K^-$ decay and also measured the lifetime of B_c^- meson in electron channel as $\tau(B_c^-) = 0.463^{+0.073}_{-0.065} \pm 0.036$ ps. The CDF experiment has also observed $B_c^- \to J/\psi \pi^-$ decay with a significance exceeding 6.5σ and has measured the mass of B_c^- meson as $M(B_c^-) = 6276.5 \pm 4.0 \pm 2.7 MeV/c^2$.

1. Introduction

1.1. Tevatron in Run-II

The Run-II data taking period at the Fermilab Tevatron collider began in 2001 with proton antiproton collisions at energy $\sqrt{s} = 1.96$ TeV. Since then data corresponding to a total integrated luminosity of about 1.6 fb^{-1} have been collected. It has also recorded highest ever instantaneous luminosity in any such hadron collider. The two interaction regions of Tevatron are instrumented with the CDF [1] and DØ [2] detectors. The state of art silicon tracking system at both CDF and DØ detectors enable to reconstruct secondary vertices which is important ingredient to identify B hardron decays.

The Tevatron is a good source of all B hadrons species including those not easily accessible at B factories. The relatively large $b\bar{b}$ production cross section is an advantage to study B physics at the Tevatron. However, the total inelastic cross section is proportionally large (10^3) as well. This makes it necessary to collect data with specific triggers. In particular, several of the B_c^- [3] decay modes contain a J/ψ in the final state and J/ψ is one of the most easily reconstructable decays owing to an efficient dimuon trigger giving high purity $J/\psi \to \mu^+\mu^-$ reconstruction both at CDF and DØ experiments.

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1.2. The B_c^- Properties

The B_c^- meson is the ground state of b and $\bar{c}$ quarks which makes it a unique system with two heavy quarks of different flavors. The presence of both such quarks impacts on the the production, decay and mass properties of the B_c^- meson. Both color singlet and color octet states contribute to the production of B_c^- meson and separating the contributions suggests a softer p_T distribution of B_c^- compared to the other B mesons [4]. The B_c^- meson is expected to have decay properties that include both a shorter c-like lifetime and a large number of possible final states [5]. Finally, the measurement of the mass of B_c^- is interesting to compare with theoretical predictions using potential models [6] and, more recent, the lattice QCD calculations [7]. All of these theoretical predictions require testing through experimental measurements.

1.3. The B_c^- in Run-I

The observation of $20.4^{+6.2}_{-5.5}$ signal events in a combined electron and muon channel by CDF at Run-I marked the discovery of the B_c^- meson [8]. From these events, CDF measured the mass and lifetime of B_c^- as $M(B_c^-) = 6.4 \pm 0.39 \pm 0.13\ MeV/c^2$ and $\tau(B_c^-) = 0.46^{+0.18}_{-0.16} \pm 0.03$ ps respectively. In addition, the relative production cross section times the branching ratio of $B_c^- \to J/\psi l^- \nu X$ with respect to $B^- \to J/\psi K^-$ decay was determined as

$\mathcal{R} = 0.132^{+0.041}_{-0.037} \pm 0.031^{+0.032}_{-0.020}$ with the assumption of hard p_T spectrum. These measurements were crude, yet were indication that the study of B_c^- properties would be very interesting at Tevatron Run-II.

2. Measurements of the B_c^- properties

At Run-II both CDF and DØ experiments have studied the B_c^- properties. The results are reported in the following sections.

2.1. Results from DØ experiment

The DØ experiment has analyzed data of total integrated luminosity of 0.21 fb^{-1} in three muon final state, $B_c^- \rightarrow J/\psi\mu^-\nu X$, where $J/\psi \rightarrow \mu^+\mu^-$. The DØ experiment observes 231 candidates including signal and residual backgrounds [9]. The backgrounds are studied in a J/ψ + track control sample. The backgrounds are broadly divided in two categories: prompt background coming from prompt J/ψ plus fake muon and non-prompt background coming from J/ψ from B mesons plus fake muon. Monte Carlo methods are used to perform a combined likelihood ($\mathcal{L}$) fit with or without the assumption of signal component. The background only fit is poor compared with the addition of signal component. The difference in $-2log\mathcal{L}$ between signal + background fit and background only fit is 60 for 5 degrees of freedom. Figure 1 shows the mass and pseudo-proper time distributions for B_c^- candidates in DØ data with contribution of prompt and non-prompt backgrounds.

The fit, where signal component is included, estimates 95 ± 12 ± 11 signal candidates. A combined likelihood fit is performed under a variety of mass hypothesis to extract mass and lifetime of B_c^- meson. A full 2D fit to the $-2log\mathcal{L}$ returned by the fit at different mass hypothesis estimates the mass and lifetime as $M(B_c^-) = 5.95^{+0.14}_{-0.13} \pm 0.34\ MeV/c^2$ and $\tau(B_c^-) = 0.448^{+0.123}_{-0.096} \pm 0.121$ ps respectively.

2.2. Results from CDF experiment

CDF has analyzed data in semileptonic decays, $B_c^- \rightarrow J/\psi l^-\nu X$, both electron and muon channels, and also in the hadronic decay, $B_c^- \rightarrow J/\psi\pi^-$, where $J/\psi \rightarrow \mu^+\mu^-$ and $l = e, \mu$.

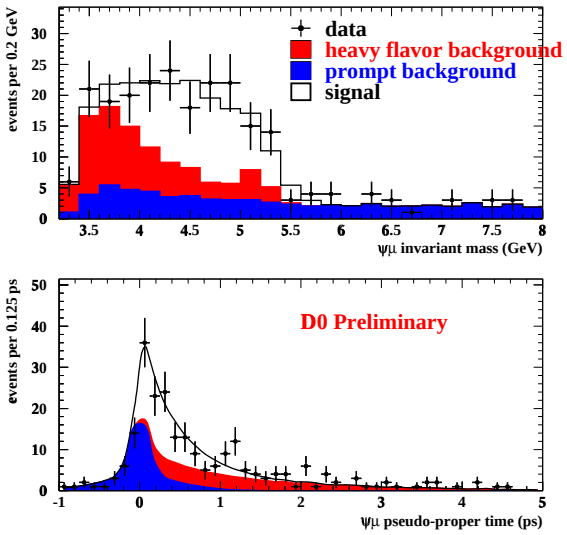

Figure 1. The invariant mass (upper) and pseudo-proper time (lower) distributions of $B_c^- \rightarrow J/\psi\mu^-\nu X$ decay in DØ data with signal and background contributions.

2.2.1. $B_c^- \rightarrow J/\psi l^-\nu X$ decay in CDF

In the semileptonic decays, $B_c^- \rightarrow J/\psi l^-\nu X$, CDF has used data of total integrated luminosity of 0.36 fb^{-1} where about 2.7 M J/ψ decays are selected. A third track, identified as muon or electron, is added to J/ψ to reconstruct the B_c^- meson.

In $B_c^- \rightarrow J/\psi\mu^-\nu X$ decay, a total of 106 candidates are observed including signal and backgrounds [10]. Both J/ψ + track and $B^- \rightarrow J/\psi K^-$ samples are used to understand the background compositions. The fake muon background is estimated from the J/ψ + track sample where the third track is misidentified as muon. The fake probability is estimated by studying $D^0 \rightarrow K^-\pi^+$ and $\Lambda^0 \rightarrow p\pi^-$ samples. The composition of K, π and p in J/ψ + track sample are estimated using PID quantities (ToF and dE/dX) at the CDF. The number

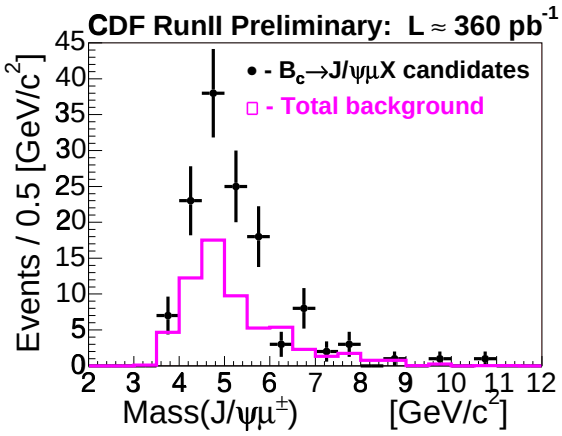

Figure 2. The invariant mass distributions of $J/\psi\mu$ in CDF data with background contribution.

of fake muons is then calculated by multiplying the fake probability with the composition. The $b\bar{b}$ background is estimated using Pythia Monte Carlo normalized to $B^- \to J/\psi K^-$ data. Finally, the sideband events of J/ψ are used, to estimate the contribution coming from fake J/ψ events. These three background processes are estimated to contribute approximately 16 (fake-μ), 13 ($b\bar{b}$) and 17 (fake J/ψ) events resulting in a 5.2σ excess of signal consisting of 60.0 ± 12.6 candidates. Figure 2 shows the invariant mass distribution of $J/\psi\mu$ obtained from CDF data with background contribution. The production cross section times branching ratio of $B_c^- \to J/\psi\mu^-\nu X$ decay with respect to $B^- \to J/\psi K^-$ decay is measured as, $\mathcal{R} = 0.249 \pm 0.045 \pm 0.069^{+0.082}_{-0.033}$ with $p_T(B) > 4$ GeV/c and $|y| < 1$.

CDF has also studied the $B_c^- \to J/\psi e^-\nu X$ decay and selected a total 179 candidates including signal and backgrounds [11]. The backgrounds in this channel are further complicated by the presence of conversion photon in addition to the fake-e, $b\bar{b}$ and fake-J/ψ backgrounds. During the reconstruction, the events which are tagged to be as photon conversion are rejected. The residual conversion is estimated from the J/ψ + tagged sample using the conversion finding efficiecy obtained from Monte Carlo. The conversion background contributes approximately 15 out of total 64 background events resulting in an excess of $114.9 \pm 15.5 \pm 13.6$ B_c^- signal candidates which corresponds to a significance of 5.9σ. The measurement of the production cross section times branching ratio of $B_c^- \to J/\psi e^-\nu X$ decay with respect to $B^- \to J/\psi K^-$ decay is measured as, $\mathcal{R} = 0.282 \pm 0.038 \pm 0.035 \pm 0.065$ with $p_T(B) > 4$ GeV/c and $|y| < 1$.

The lifetime of the B_c^- meson is also measured in the $B_c^- \to J/\psi e^-\nu X$ decay mode [12]. To have convenient parameterization of decay length, the lifetime related requirements have been relaxed during event selection compared to the $\mathcal{R}$ analysis. The decay lenght is corrected by a factor, $K = (m(B)/p_T(B))/(m(J/\psi e)/p_T(J/\psi e))$, obtained from Monte Carlo to account for the missing particles. Figure 3 shows the psedo-proper decay length distribution obtained from CDF data with signal and bacground contributions. From an unbinned likelihood fit, the lifetime of the B_c^- meson is measured as $\tau(B_c^-) = 0.463\ ^{+0.073}_{-0.065} \pm 0.036$ ps.

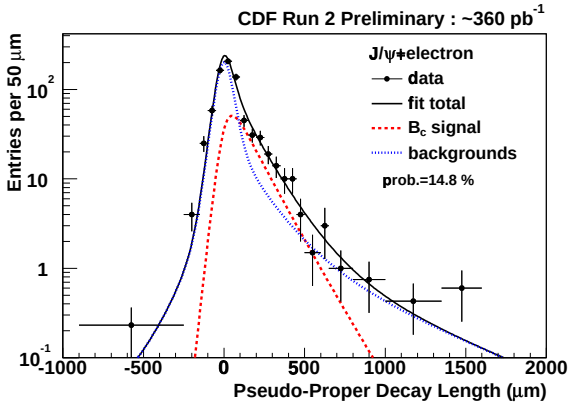

Figure 3. The pseudo-proper decay length distributions of $B_c^- \to J/\psi e^-\nu X$ decay in CDF data with signal and background contributions.

2.2.2. $B_c^- \to J/\psi\pi^-$ decay in CDF

CDF reported initial evidence of $B_c^- \to J/\psi\pi^-$ decay with 0.36 fb^{-1} [13]. Recently, CDF has analysed data of total integrated luminosity of 1.1 fb^{-1} in $B_c^- \to J/\psi\pi^-$ decay using an independent analysis and has measured the mass of B_c^- meson [14]. The analysis cuts are optimized in an unbiased way on the reference $B^- \to J/\psi K^-$ decay using first 0.36 fb^{-1} of data and the sideband background events below 5.5 GeV/c^2. The optimized cuts are then applied to analyse $B_c^- \to J/\psi\pi^-$ decay. The selection requirements include the K candidate must have an impact parameter significantly displaced from the primary vertex while simultaneously pointing toward the vertex formed by the two muons of J/ψ. A small excess of events is observed in this analysis with 0.36 fb^{-1} data and with accumalation of full 1.1 fb^{-1} data, the excess becomes more significant. A fit to the data of 1.1 fb^{-1} with Gaussian signal and linear background gives 49.1 ± 9.7 B_c^- signal events over a background of 34.1 events which corresponds to a significance larger than 6.5σ based upon simulations that include random fluctuations over a wide search window. Figure 4 shows the invariant mass distribution of $J/\psi\pi$ candidates in a mass window 5.6 to 7.2 GeV/c^2. An unbinned likelihood fit is used to extract the mass of the B_c^- meson as $M(B_c^-) = 6276.5 \pm 4.0 \pm 2.7$ MeV/c^2 compared to the prediction from lattice QCD calculation of $M(B_c^-)_{LAT} = 6304 \pm 12^{+18}_{-0}$ MeV/c^2.

3. Summary and Conclusions

Both CDF and DØ experiments at Tevatron have studied the B_c^- meson properties from the RUN-II data. The DØ experiment has measured the lifetime and the mass of the B_c^- meson in tri-muon channel. The CDF experiment has analysed data in semileptonic decays both in e and μ channels and measured the production cross section times branching ratio with respect to $B^- \to J/\psi K^-$ decay and also measured the lifetime in e-channel. The mass of the B_c^- meson has been measured in hadronic decay channel which is already challenging the prediction of Lattice QCD calculation.

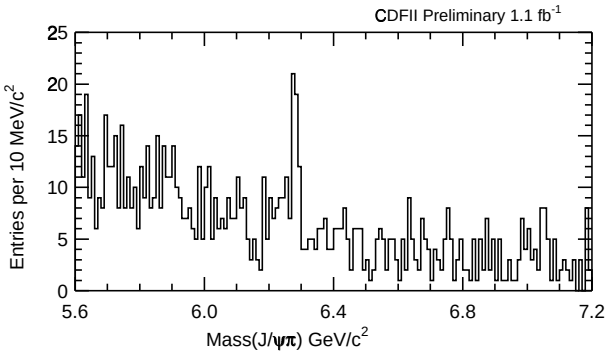

Figure 4. The invariant mass distributions of $J/\psi\pi$ in CDF data of 1.1 fb^{-1}.

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